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Comparison of Carbon Monoxide Emissions from Snowcoaches, 1997 and 2001 Snowmobiles, and 2001 Clean Snowmobile Challenge New Technology Applications

INTRODUCTION

The Montana Department of Environmental Quality (DEQ) conducted this modeling analysis to compare potential emissions from snowcoaches and different types of snowmobiles. The purpose of this analysis was to compare carbon monoxide emissions from snowcoaches, older snowmobiles, and technologically improved snowmobiles using the latest and best estimates of CO emissions. This analysis builds on information that was presented previously by DEQ in the “Preliminary Air Dispersion Modeling Analysis of Yellowstone National Park West Entrance Wintertime Carbon Monoxide Emissions” (Cain and Coefield, 1999).

Results are presented from two of the alternatives that were considered in the “Winter Use Plans Final Environmental Impact Statement (FEIS) for Yellowstone and Grand Teton National Parks, and the John D. Rockefeller Jr., Memorial Parkway.” These alternatives involved snowmobiles as the predominate transportation vehicle and snowcoaches as a replacement for all vehicles entering the park. Additional analysis is presented using data that were collected in March 2001 on a commercially available two-stroke snowmobile, and on two-stroke and four-stroke snowmobiles that were modified by university students to reduce noise and emissions.

This analysis is presented for consideration as part of the Supplement Environmental Impact Statement (SEIS) process for the winter use in Yellowstone and Grand Teton National Parks, and the John D. Rockefeller Jr. Memorial Parkway. The State of Montana has been one of the cooperating agencies with the U.S. National Park Service (NPS) for both the SEIS and FEIS.

CLEAN SNOWMOBILE CHALLENGE

In an effort to reduce snowmobile exhaust and noise, the Society of American Engineers (SAE) has organized a new intercollegiate design competition, the Clean Snowmobile Challenge (CSC). From this competition, innovative designs to improve snowmobiles have surfaced, showing the potential for new machines in the future.

The Clean Snowmobile Challenge 2001 provided university teams the latest opportunity to modify existing snowmobiles to operate cleaner and quieter. University teams used both 2- and 4-stroke engine technologies in their student-modified snowmobiles. However, given the short (4-month) time frame to adapt the vehicles, many teams had snowmobiles with poor tuning and clutching, resulting in a wide array of emissions.

The Clean Snowmobile Challenge 2001 emissions event was conducted at Flagg Ranch, Wyoming; elevation is approximately 2,092 meters (6,800 feet). Test ambient temperatures ranged from 15 to 35 degrees Fahrenheit. Southwest Research Institute conducted the emissions testing (Fussell, 2001). Test equipment included a chassis dynamometer supplied by Dynaojet of Bozeman, Montana and laboratory–grade instrumentation supplied by Southwest Research Institute, San Antonio, Texas. Fuel type for the sleds in this analysis was an ethanol blend (E-10).

Data from some of the student-modified machines were eliminated due to machine failure to meet the minimum requirements of the competition. The CO emissions analysis was conducted using a range of emissions rates for each engine speed from the top five placing snowmobiles since each machine was so unique in design (White et al., 2001). However, this range was sometimes skewed, as in the idle CO emissions factor for 4-strokes where one team did not yet have their idle mode properly set. All sleds with catalytic converters were seasoned during a 100-mile run prior to the emissions event. Most of the teams used Original Equipment Manufacturer's catalytic converters, but only two teams were able to provide an estimate on the longevity of the equipment for this snowmobile application. A chart showing the emission factors for the individual machines used in this analysis is attached as Appendix B.

The Clean Snowmobile Challenge 2001 results show the kinds of improvements in emissions that are possible from two and four-stroke engines used in snowmobiles. It is important to note that these machines are not available on the market today. Information on new technology four-stroke machines would be a useful comparison for this analysis. That information was not available when this analysis was conducted, but it will be analyzed if it becomes available.

FEDERAL AND MONTANA HOURLY CO STANDARDS

The 1-hour National Ambient Air Quality Standard (NAAQS) for CO is 35.0 parts per million (ppm) not to be exceeded more than once a calendar year. The hourly Montana Ambient Air Quality Standard (MAAQS) is 23.0 ppm for CO not to be exceeded more than once a calendar year, 34 percent less than the Federal standard. The Montana standard was based on an epidemiological evaluation conducted by Montana during 1979-1980. Other states with a different hourly CO standard than the federal one are California and New Mexico, 20.0 and 13.1 ppm, respectively.

CO HOT SPOT MODELING

An U. S. Environmental Protection Agency (EPA) “hot spot” or intersection model, CAL3QHC, was used to predict the CO concentrations from vehicles entering and exiting the park entrance during wintertime conditions. CAL3QHC is a line source dispersion model with a traffic algorithm for estimating vehicular queue lengths at signalized intersections. It predicts the concentrations of inert air pollutants such as CO from motor vehicle exhaust along the sides of the roadways one hour at a time at user-defined locations (receptors). Wind direction (from which it is coming from) can be varied from 0 to 360 degrees (at 5-degree increments) to determine the highest 1-hour CO concentration. It is considered a screening model that provides quick, worse case analysis using several broad assumptions including meteorological and site characteristics to estimate CO concentrations. Other air pollution models are available, referred to as “refined”, for a more complete, in-depth analysis that requires on-site meteorological data.

MODELING OVERVIEW

The screening model, CAL3QCH, estimates the maximum 1-hour CO concentration using one hour of data, the values are not absolute. To obtain concentrations more representative of the true atmospheric CO concentrations of an area of interest, a more refined model must be used. These more refined models use hourly vehicle data and on-site meteorology including wind direction and speed, ambient temperature, and atmospheric mixing heights. Also, at a minimum, an entire day is modeled. Topography is further characterized by defining the receptors (the locations where the model estimates the concentrations) with elevations relative to the roadway. The signalization cycle (stop and green times) used in this analysis also needs to be further studied since estimates were used. Therefore, the results from this modeling analysis should only be used as relative values for comparison among the scenarios examined specifically in this investigation.

MODELING VERSUS MONITORING

The model predicts the maximum 1-hour CO concentrations at each location (receptor) and wind direction that has been manually entered by the user; these locations represent areas where the public has access. According to the model requirements, these receptors cannot be located within 10 feet (3.0 meters) of the traveled roadways or within tollbooths (kiosks), intersections, or crosswalks. Another receptor is included to represent the local CO monitoring station if one exists. Monitoring stations are placed near the sources of pollutants according to stringent EPA siting criteria. For a microscale CO site, such as the one located at the west entrance of the Yellowstone National Park, the inlet to a CO measurement instrument must be between 2 and 10 meters (7 and 33 feet) from the roadway edge and sufficiently distant from obstacles that obstruct air flow such as buildings and vegetation to assure representative data.

The locations of the highest 1-hour CO concentrations predicted by the model will not necessarily correspond to the location of the CO monitoring station receptor. The type, number, and activity of the vehicles (entering or exiting the park entrance), and wind direction will affect where the model calculates the maximum CO concentration.

Compliance with the hourly national and Montana CO standards is determined by the second highest hourly concentration, but the model only provides the first. Therefore, the model results can only be applied as a rough estimate whether compliance with the standards will occur. Also, air pollution modeling focuses on the public's exposure to air pollution so the highest CO concentration predicted, regardless of the location, is used for comparison to the standards. In reality, the data collected at the monitoring inlet will determine the area's compliance status.

CO BACKGROUND CONCENTRATION

Generally, a background CO concentration must be added to the CAL3QHC modeling results since this model evaluates only the direct effects of CO emitted by the vehicles included in the model input file. The results do not include CO impacts from all other sources of CO that are close enough to affect the air quality of the area of interest. Indirect impacts from these sources are estimated and added to the model results as "background" CO for the final highest 1-hour concentration. These sources include CO from residential wood burning and other vehicle emissions outside the immediate area. The CAL3QHC model also does not have any way to account for residual CO still remaining in the atmosphere from the previous time period. These residual CO effects must also be factored into the background value.

Generally, a CO background concentration is obtained from direct measurement at the site of interest. In October 1998, DEQ installed a microscale carbon monoxide monitoring station (30-031-0013) on the northeast side of the Yellowstone National Park west entrance. Due to machine malfunction, minimal wintertime data were collected. The highest hourly CO concentration, 18.1 ppm (parts per million) was measured on February 13, 1999 for the 5:00 to 6:00 P.M. period. The CO concentrations decreased to 3.1 ppm for the 11:00 P.M. to 12:00 A.M. period. Reviewing the data and using DEQ professional judgement, a 5.0 ppm background CO concentration was selected to represent the worse case residual impact of CO during stagnation periods.

CARBON MONOXIDE DATA

Exhaust carbon monoxide (CO) emissions were compared from the snowcoach alternative to CSC 2001 snowmobiles and a 2001 commercially available snowmobile using the "hot spot" intersection model described above. Baseline CO emissions were estimated using the ISMA-approved 5-mode steady state laboratory methods with a 1997 fan-cooled Polaris 500cc engine (White et al., 1997), and from field evaluation of a 2001 Polaris fan-cooled 550cc 2-stroke snowmobile.

The major differences between the laboratory and field baselines were that the laboratory data were developed at 20 degrees centigrade (C) at sea level with an engine dynamometer on an older snowmobile engine using gasoline. The field data baseline information were taken at cooler and higher elevation ambient conditions on a snowmobile operating on ethanol blend fuel (E-10) and tested with a chassis dynamometer system. The 2001 snowmobile was selected randomly from the fleet of 50 snowmobiles at Flagg Ranch, Wyoming. Emissions data from CSC 2001 were also reported as brake-specific measurements of grams per kilowatt-hour as required by U.S. Environmental Protection Agency (EPA) for off-road engines, but also included dynamometer (snowmobile) track speed.

The hot spot model requires data in grams of pollutant per unit of distance (grams of CO per mile or grams of CO per hour for idling). The Pollution Prevention Bureau, DEQ, converted the snowmobile CO emissions data from the grams per kilowatt-hour to grams per mile using the raw data (White et al., 1997; Southwest Research Institute,1999) for model input. Data for the idle mode were not modified as it is reported in grams per hour.

Carbon monoxide emission factors for clean technology snowmobiles of the CSC 2001 were developed by dividing grams per hour (of emissions) for each mode by the track speed (MPH). The Pollution Prevention Bureau extrapolated the emissions rates to grams per mile. This was done by plotting grams per mile against the track speed in miles per hour with the curve extrapolated to slower speeds. For the slowest speeds, the emissions rate was assumed to be proportional to the reduction in speed. In other words, the emission factor for 5 miles per hour was half that of 10 miles per hour emission factor for a given machine.

ASSUMPTIONS

There were numerous assumptions made in the modeling demonstration including the following:

Receptors (locations where the model will estimate the CO concentration) were located on both sides of the roadway.
Wind direction varied from 0 to 360 degrees, at 5-degree increments.
All vehicles moved at a constant rate when entering the park.

Morning activity involved no departing vehicles.
Cycle time for vehicles excluding snowmobiles simulated a roadway intersection: 68 total seconds, 60 seconds red time, and 8 seconds green time.
Cycle time for snowmobiles simulated a roadway intersection: 30 total seconds, 24 seconds red time, and 6 seconds green time.

Alternatives were developed for both snowmobiles and snowcoaches, with several different scenarios developed for snowmobiles.

Snowmobile Alternatives

The following assumptions were used for each of four snowmobile scenarios. The scenarios are described at the bottom of the assumptions.

Worse Case Morning Period: 8:00 – 9:00 A.M.
600 Gasoline Snowmobiles, 10 mph; traveling emission factor = 395.0 grams per mile (gm/mi.) (Note: these snowmobiles do not stop to purchase day pass – express lane).
300 Gasoline Snowmobiles, 5 mph; traveling emission factor = 800.0 gm/mi.
Idling emission factor = 1,000.0 grams per hour (gm/hr)
10 Gasoline Snowcoaches, 5 mph; traveling emission factor = 487.0 gm/mi.
Idling emission factor = 1,000.0 gm/hr
4 18-Wheelers Diesel Trucks, 5 mph, traveling emission factor = 47.5 gm/mi.

Idling emission factor = 94.6 gm/hr

The number of snowmobiles traveling on the express is always twice the number of snowmobiles traveling on the other lane based on a conservative estimate by NPS of the number of vehicles using the express lane at the West Entrance during the 2000-2001 winter season. In the previous example, there are a total of 900 snowmobiles on the roadway.

The snowmobiles were traveling in adjacent travel lanes. The snowcoaches and trucks were traveling on one lane.

The 10 gasoline snowcoaches were existing old snowcoaches with no emissions controls. (Bishop et al., 1999.)

The trucks are included because of deliveries made to the Yellowstone National Park that pass by the entrance and the CO monitoring station, even though they do not actually enter the park.

Scenario 1: 1997 fan-cooled Polaris 500cc 2-stroke engine using conventional gasoline fuel and tested in a laboratory in San Antonio, Texas. (Alternative A from FEIS)

Scenario 2: 2001 Polaris Trail Sport fan-cooled 550cc 2-stroke snowmobile using a 10 percent ethanol 90 percent gasoline blend fuel and tested in field conditions at Flagg Ranch, Wyoming. (This is the baseline for comparison.)

Scenario 3: CSC student modified 2-stroke engines using a 10 percent ethanol: 90 percent gasoline blend fuel and tested in field conditions at Flagg Ranch, Wyoming.

Scenario 4: CSC student modified 4-stroke engines using a 10 percent ethanol: 90 percent gasoline blend fuel and tested in field conditions at Flagg Ranch, Wyoming.

Snowcoach Alternative

Worse Case Morning Period 8:00 – 9:00 A.M.

120 Gasoline Snowcoaches, 10 mph; traveling emission factor = 109.9 gm/mi. (U.S. Dept. of the Interior, 1999).

These snowcoaches are assumed to be newer snowcoaches that meet emissions standards. Consequently the emissions factor used here is less than the emissions factor for the 10 older snowcoaches considered in the snowmobile alternatives. There are not sufficient numbers of snowcoaches available today for a fleet of 120, so additional new snowcoaches would have to be purchased if this alternative was selected.

A more complete description of the modeling assumptions is in Appendix A.

RESULTS AND DISCUSSION

The original 1999 modeling analysis indicated that the vehicle fleet comprising 900 snowmobiles (1997 model year) produced the highest 1-hour CO concentration, 42.2 parts per million (ppm) or 47.2 ppm including the 5.0 ppm background CO concentration. Without the background CO concentration, the source contributions by the three different types of vehicles were snowmobiles (96.0 percent), snowcoaches (4.0 percent), and diesel trucks (0.0 percent); the snowmobiles and snowcoaches contributed 40.5 and 1.7 ppm, respectively

The model estimated the highest 1-hour CO concentration from the snowcoach alternative, a fleet of 120 snowcoaches, was 1.1 ppm or 6.1 ppm with the background CO concentration. For comparison, the 1-hour National Ambient Air Quality Standard (NAAQS) and the Montana Ambient Air Quality Standard (MAAQS) are 35.0 and 23.0 ppm, respectively, which can not to be exceeded more than once a year.

Including the background CO concentration, the fleet of 900 snowmobiles (1997 model year) caused 25.9 and 89.0 percent greater CO concentrations than the NAAQS and MAAQS, respectively, thereby violating both standards. Corresponding percentages for the snowcoach fleet were 82.6 and 73.5 percent less than the federal and state standards, respectively.

These comparisons use the emissions data from the 1999 report. An additional comparison was done for the 1997 snowmobiles and is shown in

Table 1 as “1997 Snowmobile Industry.” This comparison is made because DEQ was informed by industry that the CO emission factors for 5 and 10 mph used in the 1999 analysis needed to be changed to reflect the specific engine and power use at those speeds. These new industry numbers were applied to the 2001 baseline and CSC analysis. DEQ shows both the original 1999 emissions factors and the newer industry emissions factors for the 1997 snowmobiles. This allows a comparison to be made to the various snowmobile alternatives used in this analysis, and to compare back to the emissions factors used in the 1999 analysis.

The additional modeling analysis with both sets of emissions factors for the 1997 snowmobiles also shows what impact the new emissions factors would have had if they had been applied in the 1999 analysis. The results show some reduction in the atmospheric CO concentration, however, both the federal and state standards would still be violated. So, there is no impact on the conclusions reached in the 1999 report.

Travel speeds affect the amount of CO emitted (emission factor) from a vehicle exhaust. A CO emission factor (E_f) estimates the amount of carbon monoxide emitted from the vehicle’s exhaust while moving (grams of CO per mile) or idling (grams of CO per hour). The snowmobiles traveled at three different speeds in the fore-mentioned analysis: 0 (idle), 5, and 10 miles per hour (mph). The highest amount of carbon monoxide is emitted during idling and decreases with increasing travel speed from 5 to 10 mph.

The 2001 Polaris fan-cooled 550cc control 2-stroke snowmobile was selected by the CSC Board of Directors as the typical touring sled snowmobile in the greater Yellowstone area. Emissions data from this snowmobile were used as the best estimate of what is available currently. Due to these reasons, this class of snowmobile was selected the "baseline" for comparison to the other types of snowmobiles. This snowmobile was selected at random from the Flagg Ranch rental fleet. This fleet was calibrated to run rich (high CO) for reliability and durability in the altitude and temperature conditions.

Table 1 displays the emissions testing conditions (fuel type, ambient temperature, elevation, and environment), CO emission factors (E_f) for snowcoaches, and 2001 CSC and 1997 snowmobiles, travel speeds, and the percentage reduction (or increase) of the 2001 CSC and 1997 snowmobile emission factors relative to the 2001 2-stroke baseline emission factors. The relationships (ratios) between the 2001 CSC and 1997 snowmobiles to the 2001 2-stroke baseline emission factors are also provided in brackets. The HI refers to the highest level for all machines in that category while the LO refers to the lowest level for all machines in that category. Note that the units are different for the idle mode (grams per hour) and the other travel speeds (grams per mile).

Table 1. Emissions testing conditions (fuel type, ambient temperature, elevation, and environment), CO emission factors (E_f) for the various types of snowmobiles and travel speeds, and the percentage reduction (or increase) of the snowmobile and snowcoach emission factors relative to the 2001 2-stroke baseline emission factors. The relationships (ratios) between the snowmobiles to the 2001 2-stroke baseline emission factors are also provided in brackets. Shaded cells in table denote the reference snowmobile.

Snow-mobile Type	Fuel Type	Emis. Test Temp. (F)	Emis. Test Elev. (meter; feet)	Emis. Test Env.	Idle CO Emission Factor (g/hr)* [ratio E_f to Baseline E_f] LO	HI	Percentage Change Relative to the Baseline Idle E_f (%) LO	HI	5 mph** CO Emission Factor (g/mi.)*** [ratio E_f to Baseline E_f] LO	HI	Percentage Change Relative to the Baseline 5 mph E_f (%) LO	HI	10 mph CO Emission Factor (g/mi.) [ratio E_f to Baseline E_f] LO	HI	Percentage Change Relative to the Baseline 10 mph E_f (%) LO	HI
1997 Snow-mobile	Gas	60	184.6, 600	Lab	1000.0 [1.3]		25		800.0		99		395.0		96	
1997 Snow-mobile Industry	Gas				1000.0 [1.3]		25		111.0		94		224.0		94	
2001 2-Stroke Baseline	E-10	15 – 35	2,092; 6,800	Field	746.6		------		7.2		------		14.5		------	
2001 CSC New Tech. 2-Stroke	E-10	15 – 35	2,092; 6,800	Field	260.2 [0.3485]	2,135.0 [2.8596]	-187	65	0.4 [0.0556]	0.8 [0.1111]	- 1,700	- 800	0.9 [0.0621)	1.7 [0.1172)	- 1,511	- 753
2001 CSC New Tech. 4-Stroke	E-10	15 – 35	2,092; 6,800	Field	2.0 [0.0027]	697.0 [0.9336]	- 37,230	- 7	0.1 [0.0139]	18.0 [2.5000]	- 7,100	60	0.27 [0.0186)	36.0 [2.4828)	- 5,270	60
Snow-coach	Gas	22	2,012; 6,600	Field	N/A****		N/A		N/A		N/A		109.9		87	

* g/hr = grams per hour.
** mph = miles per hour.
*** g/mi. = grams per mile.
**** N/A = not available.

Table 2. The number of snowcoaches or snowmobiles, the highest estimated 1-hour CO concentrations produced by the fleet in the scenario, and the percentages of the estimated CO concentrations to the 1-hour NAAQS and MAAQS (ratios). The percentage contributions of the snowcoach or snowmobile emissions to the total 1-hour CO concentrations are given in brackets. The snowcoaches do not stop. Assumed that the number of snowmobiles traveling through the park entrance without stopping was twice as many as those that stopped at the entrance to get day pass. The background CO concentration (5.0 ppm) is included.

Number of Snowcoaches or Snowmobiles No Stopping /Stopped (Total)	Snow-coaches Only CO Conc. (ppm)	Percentage (%)* NAAQS	Percentage (%)* MAAQS	Industry 2-Stroke Snowmobile CO Conc. (ppm) [% Contribution by Snowmobiles]	Percentage (%)* NAAQS	Percentage (%)* MAAQS	Baseline 2-Stroke Snowmobile CO Conc. (ppm) [% Contribution by Snowmobiles]	Percentage (%)* NAAQS	Percentage (%)* MAAQS	New Tech. 2-Stroke Estimated CO Conc. (ppm) [% Contribution by Snowmobiles] LO	New Tech. 2-Stroke HI	Percentage (%) NAAQS LO	NAAQS HI	MAAQS LO	MAAQS HI	New Tech. 4-Stroke Estimated CO Conc. (ppm) [% Contribution by Snowmobiles] LO	New Tech. 4-Stroke HI	Percentage (%) NAAQS LO	NAAQS HI	MAAQS LO	MAAQS HI
100/50 (150)	5.9	16.9	25.7								16.6 [46.4]	N/A	47.4	N/A	72.2						
200/100 (300)	6.8	19.4	29.6								24.0 [64.2]	N/A	68.6	N/A	104.3						
300/150 (450)	7.7	22.0	33.5	21.6 [60.2]	61.7	93.9					31.1 [72.4]	N/A	88.9	N/A	135.2						
400/200 (600)	8.6	24.6	37.4	25.0 [68.8]	71.4	108.8					36.7 [79.8]	N/A	104.9	N/A	159.6						
500/250 (750)	9.5	27.1	41.3	29.4 [75.9]	84.0	127.8					42.7 [84.3]	N/A	122.0	N/A	185.7						
600/300 (900)	10.5	30.0	45.7	31.5 [78.7]	90.0	137.0	20.5 [67.3]	58.6	89.1	11.6 [38.8]	45.0 [85.1]	33.1	128.6	50.4	195.7	8.9 [0.0]	20.3 [65.0]	25.4	58.0	38.7	88.3
700/350 (1,050)	11.4	32.6	49.6	33.1 [79.8]	94.6	143.9	20.9 [67.9]	59.7	90.9	11.7 [39.3]		33.4	N/A**	50.9	NA	8.9 [0.0]	20.8 [67.8]	25.4	59.4	38.7	90.4
800/400 (1,200)	12.3	35.1	53.5	34.5 [80.6]	98.6	150.0	21.2 [68.4]	60.6	92.2	11.7 [37.6]		33.4	N/A	50.9	NA	8.9 [0.0]	21.2 [68.4]	25.4	60.6	38.7	92.2
900/450 (1,350)	13.2	37.7	57.4	35.8 [81.3]	102.3	155.7	21.4 [68.7]	61.1	93.0	11.7 [37.6]		33.4	N/A	50.9	NA	8.9 [0.0]	21.5 [68.8]	25.4	61.4	38.7	93.5
1000/500 (1,500)	14.1	40.3	61.3				21.5 [68.8]	61.4	93.5	11.7 [37.6]		33.4	N/A	50.9	NA	8.9 [0.0]	21.6 [69.0]	25.4	61.7	38.7	93.9
1100/550 (1,650)	15.0	42.9	65.2				21.6 [69.0]	61.7	93.9	11.7 [37.6]		33.4	N/A	50.9	NA	8.9 [0.0]	22.0 [69.6]	25.4	62.9	38.7	95.7
1200/600 (1,800)	15.9	45.4	69.1				21.7 [69.1]	62.0	94.3	11.7 [37.6]		33.4	N/A	50.9	NA	8.9 [0.0]	21.1 [69.7]	25.4	60.3	38.7	91.7

- 1-Hour CO NAAQS = 35.0 ppm; 1-Hour CO MAAQS = 23.0 ppm.
- ** N/A = Data not available OR the CO concentration exceeded the standard.

Based on the CO emission factors, the CSC new technology 2- and 4-stroke snowmobiles would produce significantly less CO, particularly from snowmobiles with the “low” range emission factors relative to the 2001 2-stroke baseline emissions factors. For the CSC 2-stroke clean snowmobiles with the low range of emission factors, CO emissions could be reduced from 180 to 1700 times with increasing speed. Corresponding values for the CSC 4-stroke snowmobiles could emit 37,000 to 5,200 times less CO emissions relative to the baseline.

The high range of emissions factors from the CSC 2-stroke snowmobiles could produce more CO during the idling phase relative to the 2001 2-stroke snowmobile, but CO emissions would be reduced 800 fold when traveling either 5 or 10 mph. Definitive estimates can not be established due to the wide range of student’s ability to properly tune their engines. However, the amounts of CO emitted by the CSC new technology snowmobile exhaust would be considerably less than the 2001 2-stroke baseline snowmobiles.

There are several explanations for the differences in the CO emission factors between the baseline 1997 and 2001 2-stroke snowmobiles. Use of oxygenated fuels use by snowmobiles can reduced CO emissions by 9 to 38 percent (White et al., 1998c). Another difference in the 1997 and 2001 emissions factors was that the 1997 laboratory data were different than the field data as field conditions are usually not repeatable, and probably have a greater day-to-day variation with the 2-stroke engines than under the lab conditions.

The data on the 2001 baseline and CSC sleds were performed on a chassis dynamometer with a procedure that was developed for an engine dynamometer. Test results were close, but would not be expected to be exactly the same as the engine dynamometer tests. For example, the 2001 results now include any inconsistencies introduced by the continuously variable transmission (CVT) that will vary the throttle settings at low speeds (under 25 mph), and thus, vary the emissions factors in the transitional area between 0 to 25 mph. In other words, the emissions factor derived at a power setting for 15 mph, will be different if the engine increases power (from 1 mph) or decreases power (as from 30 mph). In these analyses, all data were run from higher to lower power levels according to the protocol.

The snowmobiles with their corresponding CO emission factors were entered into the model, CAL3QHC, to determine the highest estimated 1-hour CO concentration. The initial model run for all of the snowmobile types was 600/300. This scenario means a total 900 snowmobiles were traveling the roadway, 600 snowmobiles did not stop (express) and 300 snowmobiles had to stop. Depending on the type of snowmobile, the number of snowmobiles varied from 100 to 1200 for those traveling on the express lane. Corresponding numbers of snowmobiles traveling on the other lane that had to stop (to purchase a day pass) varied from 50 to 600. The determining factor was whether the estimated CO concentrations from the snowmobile exhaust violated a federal or state standard; if the concentration exceeded the standard, increasing the number of snowmobiles was pointless. Table 2 presents the number of snowmobiles, the highest modeled 1-hour CO concentrations produced from their vehicle emissions, and percentages of these CO concentrations to the NAAQS and MAAQS.

The air dispersion model calculates the CO concentrations at every designated point along both sides of the roadway. Changing the direction the wind is coming from determines which point has the highest 1-hour CO concentration. Under most wind directions, snowmobiles were responsible for the highest concentrations. However, snowcoaches were the primary contributor to total CO under certain wind directions. The only comparable CO emissions to the emissions from snowcoaches alone was from the CSC new technology 4-stroke snowmobiles (low range) where the model indicated that essentially only the snowcoaches contributed to the atmospheric carbon monoxide concentrations.

CONCLUSIONS AND RECOMMENDATIONS

From this analysis the following conclusions were developed:

The 2001 550cc snowmobile tested in field conditions using ethanol fuel performed significantly better than the 1997 500cc snowmobile using regular gasoline fuel. Since the testing conditions were different it is not possible to draw absolute conclusions for the improvements. It is likely that the improvements were due to a combination of efficiency improvements by industry, fuel type, cold temperature field-testing, and a change in the way the dynamometer testing was conducted.

The baseline 2001 snowmobile data were representative of actual operating conditions and will be a better comparison for alternatives developed in the Supplemental Environmental Impact Statement (SEIS).

The snowcoach alternative produced a lower peak 1-hour CO concentration than any number of the baseline 2001 snowmobiles evaluated.

New clean snowmobile technologies demonstrated at the Clean Snowmobile Challenge 2001 could significantly reduce carbon monoxide emissions from snowmobiles. These reductions are available from both two-stroke and four-stroke machines modified by university students, but not yet commercially available. The competition illustrated the potential of emissions reductions, however the machines were designed for trail riding and are not representative of the fuel range of commercially available snowmobiles.

Up to 750 snowmobiles with emissions similar to the **low** emissions range of CSC 2-stroke snowmobiles, using ethanol blend fuel, and with two-thirds using the express lanes, would produce a lower peak 1-hour CO concentration than the snowcoach alternative.

Ambient CO levels would be expected to exceed the MAAQS 1-hour CO standard (by 129 percent) with less than 150 snowmobiles having emissions similar to those estimated for the **high** range of CSC 4-stroke type snowmobiles. (This is based on using the snowcoach alternative from the first report estimating the highest 1-hour CO concentration at 1.1 ppm).

Up to 750 snowmobiles with emissions similar to those of the CSC 4-stroke snowmobiles with two-thirds using pre-paid passes would produce a lower peak 1-hour CO concentration than the snowcoach alternative.

However, the emissions results for the CSC snowmobiles are based on individually modified snowmobiles, not fleets. Whether the technologies applied to these machines can be reproduced on a mass production scale is unknown, but the competition did require the modifications to be cost effective and practical. The true test would be for a fleet composed of the CSC 2-stroke snowmobiles using the ethanol blend to be used in Yellowstone National Park for several winter seasons under “normal” maintenance and use.

Further air dispersion modeling using currently available industry developed four-stroke engines is needed to better determine the effects of new technologies on carbon monoxide emissions.

Recommendations

Additional information needs to be obtained on new technology snowmobiles from manufacturers, particularly the 4-stroke machines that are currently operating in Yellowstone National Park, Grand Teton National Park, and John D. Rockefeller Jr. Memorial Parkway. Modeling analysis should be completed with this industry information. The evaluation of the

Clean Snowmobile Challenge data shows what might occur in the future. However, information from the manufacturers on current production vehicles would be the best method to determine what emissions reductions are likely within the next few years.

Develop a process for student teams to better tune and adjust their competition snowmobiles to reduce the emissions variability. The large range of emissions, especially at idle, illustrates that more time and tuning is needed to eliminate the randomness of emissions.

Continue the use of ethanol fuels in snowmachines. This fuel reduces the carbon monoxide emissions without impact to the snowmobile operator.

REFERENCES

Bishop, G.A. and D.H. Stedman. 1998. *1998 Preliminary Snowmobile Emission Survey in Yellowstone National Park: Final Report*. Prepared for the National Park Service. University of Denver. Denver, Colorado. http://www.westbioenergy.org/snow/index.htm

Bishop, G. A., D. H. Stedman, University of Denver, and M. Hektner, J. D. Ray, National Park Service. 1999. *An In-Use Snowmobile Emissions Survey in Yellowstone National Park*. American Chemical Society Environmental Science & Technology Vol 33, No 21, pages 3824-3826.

Cain, Cyra J. and John Coefield. 1999. Preliminary Air Dispersion Modeling Analysis of Yellowstone National Park West Entrance Wintertime Carbon Monoxide Emissions. Monitoring and Data Management Bureau, Planning, Prevention and Assistance Division, Montana Department of Environmental Quality.

Carroll, J.N. and J.J. White. 1999. *Characterization of Snowmobile Particulate Emissions: Final Letter Report*. Prepared for the Yellowstone Park Foundation, Inc., by Southwest Research Institute. Report number SwRI 08-2457.

Department of Environmental Quality, by Southwest Research Institute. Report number SwRI 7383, DEQ number EDG-95-7383, and DOE number DE-FG51-95R020683.

Fussell, Lori M. 2001. The Society of Automotive Engineers Clean Snowmobile Challenge 2001 Final Report, Montana Department of Environmental Quality and the Institute of Science, Ecology, and the Environment. Helena, Montana.

Morris J.A., G.A. Bishop, and D.H. Stedman. 1999. *Real-time Remote Sensing of Snowmobile Emissions at Yellowstone National Park: An Oxygenated Fuel Study, 1999.* Prepared for Western Regional Biomass Energy Program, Lincoln, NE. University of Denver, August 1999. (Bishop, G.A. and D.H. Stedman. 1998. Appendix A of this report)

U.S. Department of the Interior. 1999. Winter Use Plan Draft Environmental Impact Statement for the Yellowstone and Grand Teton National Parks and John D. Rockefeller Jr., Memorial Parkway. National Park Service.

U.S. Environmental Protection Agency. 1985. Compilation of Air Pollutant Emission Factors – Volume II: Mobile Sources. Office of Mobile Sources, United States Environmental Protection Agency, AP-42, Fourth Edition.

U.S. Environmental Protection Agency. 1992. Screening Procedures For Estimating The Air Quality Impact Of Stationary Sources, Revised. Office of Air and Radiation, Office of Air Quality Planning and Standards. United States Environmental Protection Agency. Research Triangle Park, NC. EPA-454/R-92-019.

U.S. Environmental Protection Agency. 1998. Emission Facts: Idling Vehicle Emissions. Office of Mobile Sources, United States Environmental Protection Agency, EPA420-F-98-014.

White, J.J. 2001. Emissions Testing for the 2001 Clean Snowmobile Challenge, SwR08.04294. Southwest Research Institute and the Institute for Science, Environment and Ecology. Jackson, Wyoming.

White, J.J., J.N. Carroll, and H. E. Haines. 1998. *Emissions from Snowmobile Engines Using Bio-based Fuels and Lubricants.* Montana

Wright, C.W, and J.J. White. 1998. *Development and Validation of a Snowmobile Engine Emission Test Procedure.* SAE Technical Paper Series 982017. International Off-Highway and Powerplant Conference and Exposition. Milwaukee, Wisconsin, September 14-16, 1998.

APPENDIX A. Snowmobile and Bombardier (snowcoach) Carbon Monoxide Emissions and Air Dispersion Modeling Assumptions.

Snowmobile:

Alternative A: Baseline Gasoline CO Emissions:

Vehicle Miles/Hour	**Grams/Mile**	**Grams/Hour**
0	NA [a]	1000
5	1741	NA
15	580	NA
25	348	NA
35	249	NA

[a] NA = not applicable.

Source: U.S. Department of the Interior. 1999, p. 27, White et al., 1998.

Calculation for 5 mph: The model, CAL3QHC, truncates all CO emission factors greater than 1,000 to 1,000 so the 5 mph emission factor became 1,000 grams per mile.

Calculation for 10.0 mph: Graphed the 4 points on graphing paper. Estimated a curvilinear line through all 4 points since it is well known that this relationship exists between CO emissions and with vehicle speed (mph). An 800 gm/mi. emission factor was approximated and used.

Snowcoach:

Bombardier High Altitude Light Duty Gasoline Truck for CO at 5.0 mph = 1,526.06 gm/mi., 25° F, 100% cold starts, calendar year = 1980 since the Bombardier that have no emission controls similar to pre-1970 V-8 and the tables do not precede 1980. Used maximum allowed CAL3QHC CO emission factor = 1,000.0 gm/mi. (Compilation of Air Pollutant Emission Factor – Volume II: Mobile Sources, Table J-27). Idling for CO = 487.0 gm/hr winter conditions: 30° F, 13.0 psi RVP gasoline (Emission Facts: Idling Vehicle Emissions). Appendix J High Altitude not available for 25.0 mph, but have Tables J-29 and J-30 High Altitude for 19.6 and 35.0 mph, respectively. Averaged the data for the two types of Snowcoaches and prorated based on number of each type. 10 Bombardier; High Altitude, Light Duty Gasoline Truck for CO at 25 mph = 293.46 gm/mi. (19.6 mph) + 192.72 gm/mi. (35.0 mph) = 486.18/2 = 243.1 gm/mi., 25° F, 50% cold starts 50% stabilized 50% hot starts, calendar year = 1980. Gasoline Snowcoaches in Lanes 1 and 2 at 10 mph; traveling emission factor = 109.9 gm/mi. (DEIS p. 38). No table available for 15 miles per hour (MPH). Graphed 5.0, 10.0, 19.5 and 35.0 MPH, 25° F, 100% cold starts, calendar year = 1980, and approximated 15 MPH = 630 gm/mi. (Compilation of Air Pollutant Emission Factor – Volume II: Mobile Sources, Tables J-27 - 30).

Appendix B

Clean Snowmobile Challenge 2001

Additional Data

Co emissions Factors	Idle CO Emission Factor (g/hr)	5 mph CO Emission Factor (g/mi.)	10 mph CO Emission Factor (g/mi.)	25 mph CO Emission Factor (g/mi.)	mph (g/mi.)	mph (g/mi.)	mph (g/mi.)
Baseline	746.60	7.23	14.45	34.72	@ 32.00 mph 43.40	@ 50.00 mph 145.50	@ 70.00 mph 215.70
2001 Polaris Trail Sport 550cc on ethanol blend fuel							
CSC 2-Stroke MSU-Mankato	2135.00	0.43	0.85	2.13	@ 42.00 mph 3.57	@ 52.00 mph 44.54	@ 75.00 mph 326.07
Waterloo	260.20	0.83	1.65	4.13	@ 32.00 mph 5.28	@ 46.00 mph 74.09	@ 70.00 mph 250.56
Range 2-Stokes	260.00-2,135.00	0.40-0.80	0.90-1.70	2.10-4.10	*for new technology 2-strokes w cat		
CSC 4-Stroke Buffalo	93.10	16.50	33.00	54.09	@ 22.00 mph 66.00	@ 35.00 mph 14.40	@ 55.00 mph 2.90
Idaho	697.00	18.00	36.00	70.80	@ 21.00 mph 71.00	@ 36.00 mph 70.00	@ 60.00 mph 123.00
Kettering	2.00	0.14	0.27	0.68	@ 44.00 mph 1.20	@ 55.00 mph 33.70	@ 71.00 mph 256.30
Range 4-Strokes	2.00-697.00	0.10-18.00	0.27 to 36.00	0.38 to 71.00	*for new technology 4-strokes		

*4-strokes emissions have been improved 40 to 60 percent if tuned properly,
*and of these, only Kettering had an engine with OEM supplied catalyst and controls.
Wyoming and Colorado School of Mines were too underpowered.
Clarkson's entry had commercial reliability problems that would effect emissions.